AN EXPERIMENTAL STUDY OF THE IMPACT DISRUPTION OF A POROUS, INHOMOGENEOUS TARGET

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The fragmentation of asteroids has been linked to the production of interplanetary dust particles by the infrared observation of dust bands associated with major families of asteroids in the main-belt [1]. Kortenkamp *et al*. [2] have modeled the orbital evolution of the dust from these dust bands and concluded that the dust associated with the Themis and Koronis families of asteroids constitutes approximately half of all the interplanetary dust incident on the Earth. Thus, a detailed understanding of the dust production by the catastrophic disruption and subsequent comminution of asteroids is required to understand the interplanetary dust population at Earth.

Themis is a C-type asteroid while Koronis is an S-type asteroid. While the S-type asteroids have no definitive spectral match among the meteorites, the C-type asteroids have reflectance spectra similar to carbonaceous chondrite meteorites, which are inhomogeneous assemblages of olivine chondrules, a few millimeters in size, distributed in a fine-grained matrix. The matrix is generally more friable than the chondrules. Many of the chondritic meteorites exhibit significant porosity. For example, Britt and Consolmagno [3] report a bulk density of 1.6 g/cm^3 for the Orgueil CI chondrite, much lower than the densities of its mineral constituents. Thus, we expect the asteroidal parent body of Orgueil to be inhomogeneous and porous. Few experiments have been performed to study the disruption of inhomogeneous assemblages of two materials of different strengths and which exhibit significant porosity. This experiment is intended as the first in a series, in which meteorite analogs and then meteorite samples will be impacted to investigate the fracture mechanics of the meteorite parent bodies and to investigate the dust production from the disruption of these parent bodies.

The catastrophic disruption was simulated by impacting a rock target with a high-speed projectile. A porphyritic olivine basalt from Hawaii was selected for the first series of disruption experiments because it exhibited two features similar to the carbonaceous chondrite meteorites: (1) it consists of large olivine phenocrysts, typically a few millimeters in size, in a weaker, finer-grained matrix, and, (2) it exhibits significant porosity, with observable vesicles. Three samples of the basalt were disrupted by firing 1/4 inch diameter aluminum spheres at them at a speed of ~5 km/s using the Ames Vertical Gun Range (see Table 1).

To avoid secondary fragmentation when the primary fragments scatter off the walls of the chamber, we located “passive monitors” around the chamber. Each passive monitor consisted of an aerogel capture cell ~1″ x 1.5″ in area and three foils: 4 µm thick polypropylene, 7 µm thick Kapton, and 18 µm thick aluminum. Each aerogel collector was ~1 inch thick, allowing the intact capture of fragments up to several millimeters in size. Since the matrix and the olivines of this Hawaiian basalt have different chemical compositions, each captured fragment will be analyzed in-situ, using a technique developed to perform in-situ analysis of interplanetary dust and space debris [4]. The material not captured by the aerogels was recovered from the floor of the chamber after each shot. The foils were selected to be thin enough so that high-speed fragments would penetrate, providing a size distribution of the debris. Each disruption was also photographed, at 500 frames/s, allowing an estimate of the velocity of the bulk of the debris.

The preliminary results from the examination of the high-speed photography, several foils, the fragments recovered from the chamber, and one aerogel are reported here.

High-speed Photography. An estimate of the ejection speeds for some particles from two of the shots (96100l and 961002) can be made from the analysis of the 500 frames/s video. For shot 961001, a speed of 38 m/s was determined from the 0.012 second time delay between target disruption and the first indication of dust impact-induced flexure of the particle detector mounted 18 inches from the target. We found a similar ejection speed of 30 m/s for shot 961002 from a flash of light reflected from the deformation of an aluminum foil caused by the impact of a larger particle (>2 mm in diameter). Detailed analysis of 500 frames/s film footage will provide ejection velocities for a number of individual fragments.

Foils. Optical examination of the foils revealed no cleanly cut holes punched out by high-speed particles. The few particles which did penetrate the polypropylene and kapton foils appear instead to have torn their way through, leaving small “flap doors” in the foils. The majority of the particles striking the foils appear to have shattered upon impact with the detector, leaving fragments adhering to the inner surfaces of small depressions in the foils. These results indicate that the particles produced in these experiments had lower speeds than those reported by Nakamura *et al.*

[5] for fragments 10 to 100 µm in size produced by impacting a non-porous target. The low speeds inferred from the absence of clean punctures in the foils are consistent with the low ejection speeds derived from the high-speed photography. Our results are also consistent with those of Love *et al*. [6] indicating lower fragment ejection speeds for porous targets.

Fragments. All three impacts were in the super-catastrophic regime [7], with largest fragment masses less than a few grams ($f_l \approx 0.01$). The largest fragments were representative samples of the target material, comprised of centimeter-sized pieces of matrix with intact olivine phenocrysts. At the millimeter scale, however, the fragments collected from the chamber included shards of matrix material, olivine crystals with attached matrix, and isolated, intact olivine crystals. One ~5 mm fragment of basalt matrix was found in the shape of a small cup, from which an olivine phenocryst apparently separated intact. This fragment and the large number of isolated, intact olivine crystals among the impact debris indicates preferential material failure along matrix/phenocryst boundaries at scales comparable to the size of the phenocrysts.

Aerogel. Preliminary optical examination of one aerogel collector, located ~45 inches from the target in shot 961001, identified 9 captured fragments ≥100 µm in size. Two of these are opaque and small (each <200 µm), resembling fragments of the matrix. One is a transparent sphere ~100 µm in size. The remaining 6 are all transparent shards, resembling olivine fragments, ranging from 300 to 700 µm in size. One has a small amount of dark material distributed along an edge. If the chemical analysis determines that these transparent fragments are all dominated by olivine, then olivine would be overrepresented in these captured fragments compared to its proportion in the host rock.

If these results are directly applicable to asteroids having a carbonaceous chondrite structure, then the preliminary results suggest that those asteroids might preferentially overproduce olivine-rich debris at the size scale of the chondrules and that olivines might be underrepresented in the debris at substantially smaller sizes. Further experiments, using meteoritic material as the targets, are required to understand the catastrophic disruption of inhomogeneous, porous targets and the contribution of chondritic parent bodies to the interplanetary dust.

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Table 1. Experimental Conditions

Shot #	Target Mass (g)	Impactor	Speed (km/s)
961001	273.0	1/4″ Al	5.50
961002	356.5	1/4″ Al	5.05
961004	674.0	1/4″ Al	5.36